LA-UR-19-29629

Title: Visualization of Theoretical Radiation Source Transmission Thru Simulated Concrete Buildings

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Intended for: Correspondance
Report

Issued: 2019-09-24

Visualization of Theoretical Radiation Source Transmission Thru Simulated Concrete Buildings

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CCS-6

23 September 2019

1. Introduction

Issac Michaud presented a talk at LANL on March 12th of 2018 and published his thesis in 2019, Michaud, I. (2019). Michaud and others, see Ştefănescu, R., Hite, J., Cook, J., Smith, R. C., & Mattingly, J. (2019), have worked further on a similar problem. This is not an exhaustive list, although the references in [2] provide other related works. These works demonstrate how Bayesian analysis may be used to determine optimal locations of radiation sensors. The purpose of this document is to provide an intuition as to why and were these sensors may be located by understanding the theoretical result of radiation source transmission through concrete buildings.

2. Graphics Example: Source Strengths and Buildings

Consider the situation where we have radiation sources in an area. Five sources are placed randomly in the inner location of the area and shown in Figure 1. Each source is provided a random strength, in this case the strengths are, 21, 75,40 ,19 ,75, for sources 1 thru 5 respectively. The absolute source strengths are not provided. One reason for not providing units for source strengths is to show the methodology and not focus on the magnitudes. A second reason is that this methodology may be used at many length scales and various strength amounts. This example has 20 rows and 40 columns each unit representing 1 meter of length. Appendix 1 contains an example with only a single source. Appendix 2 contains an example with an are of 100 meters by 100 meters.

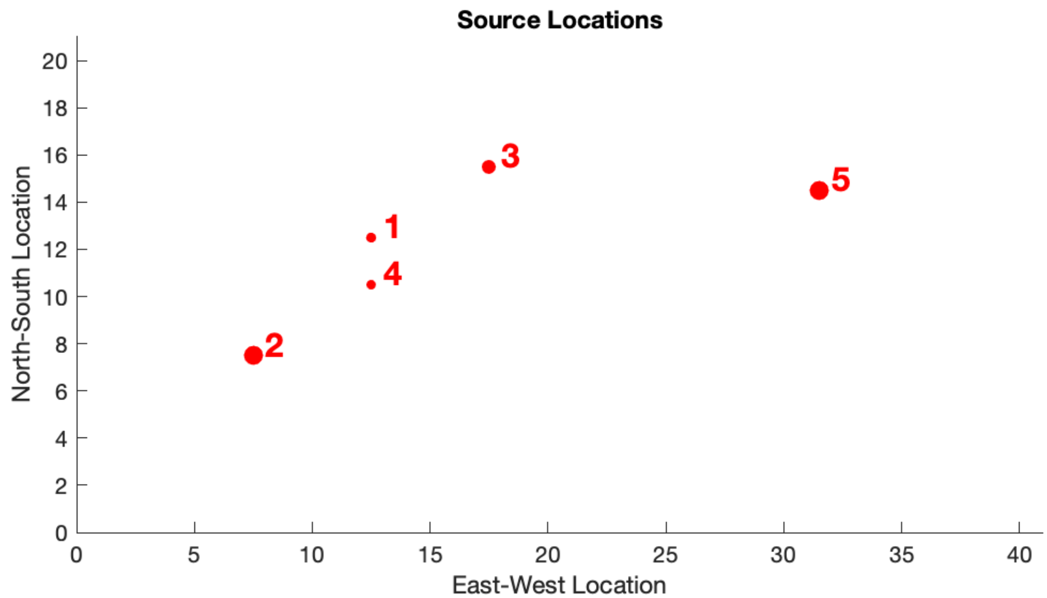


Figure 1: 5 Sources placed randomly in an area of 20 by 40 area where the length units are not specifically specified. The size of the source is proportional to the size of the dot.

In the Figure 2 are overlaid rectangles that are meant to represent buildings in the area of the sources and the surrounding area. The rectangles, source locations and source strengths are chosen arbitrarily (at random and selected as useful for demonstration purposes).

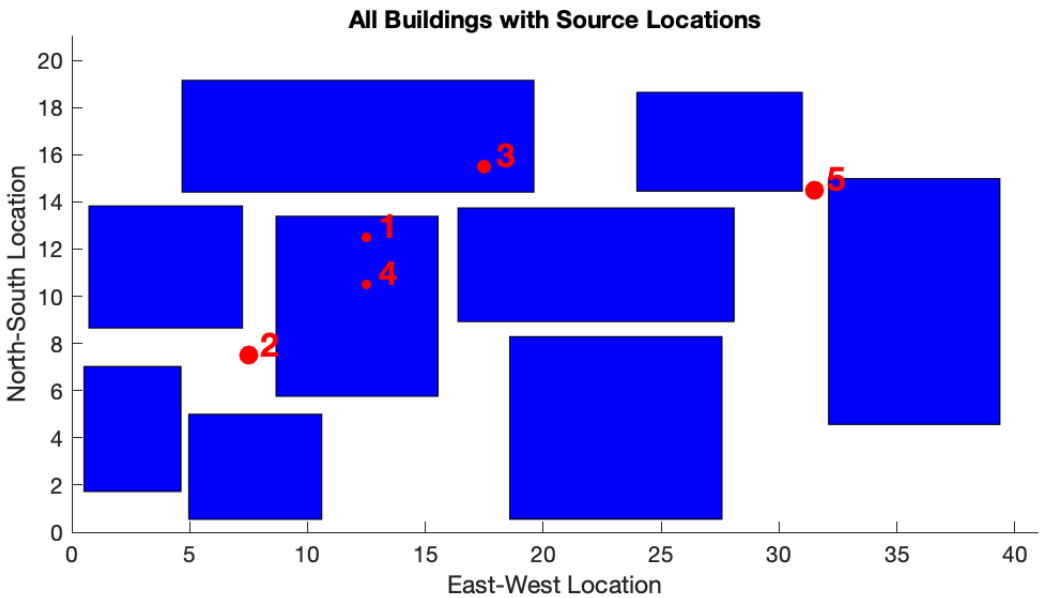


Figure 2: Random locations and sizes of buildings, buildings located in an area to contain the sources locations and their surrounding area, with sources as in Figure 1.

The task is to determine the radiation that is transmitted throughout the area. To do this assume the source is Cesium-137 and the building are made of concrete. We assume the density of concrete is the same for all buildings, that is, outer and inner walls. Ignore the attenuation due to other materials and air.

From [5] page 22 the I/I_0 =.796/cm for concrete. A value of around .8 /cm (.796 is used here) transmission is found in [5], [6], and [7]. Solving μ = - log(.796) = .228 to determine the attenuation coefficient for cement. Assume the distance is in meters, rather than cm, and the attenuation transmission for Cesium-137 is .228 per cm for concrete. Assume the building is 1% concrete, this means that each meter of building, centimeter of concrete, has an attenuation transmission of .228 per meter of building. The overall transmission through the concrete is $.228^{\text{distance in concrete(in cm)}}$.

3. Graphics Example: Attenuation with Distance and Transmission Thru Buildings

Each source has a transmission that falls of as an inverse square law with distance. The transmitted radiation is provided in Figures 3-7 for each of the 5 sources. In this analysis we assume the transmission through air is negligible and hence is 100%. The radiation strength is computed on a grid that is 20 rows by 40 columns. The grid square that contains the source has an area of 1. The source strength is arbitrarily assigned an "average" value for that area of .75 times the source strength. To provide a better scaling, logarithms of the radiated amount are used in the graphics.

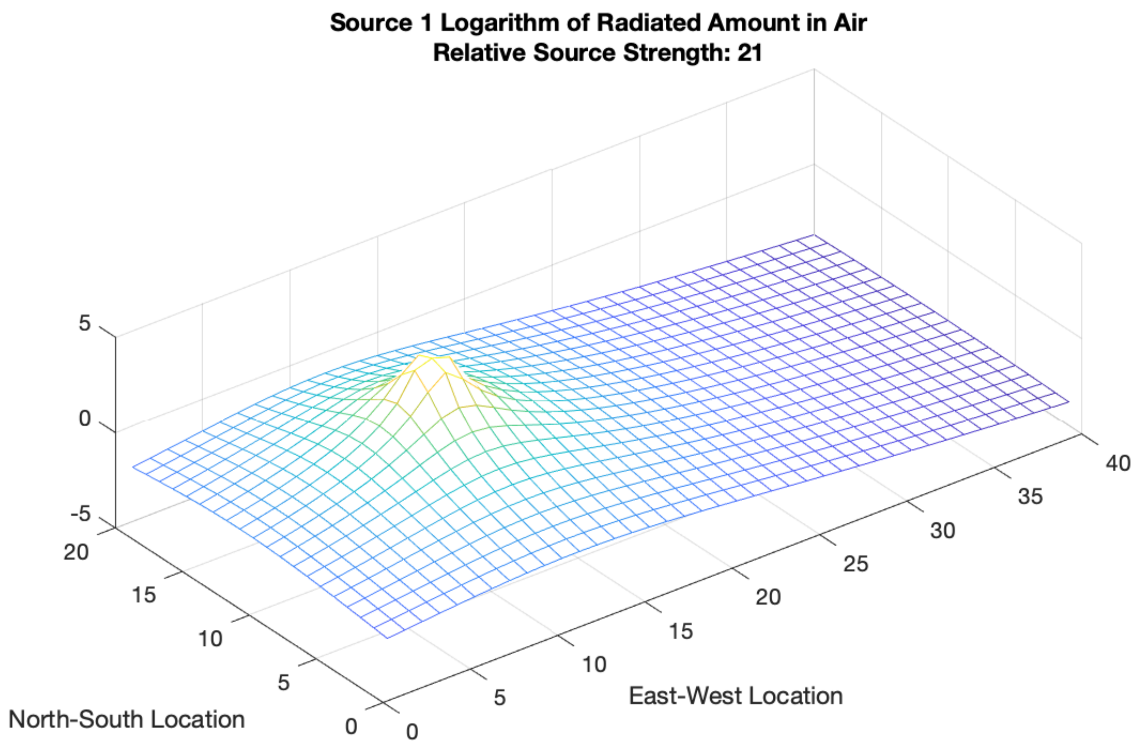


Figure 3: Natural Logarithm of the Radiated Amount from a Source of Strength 20 in Location 1.

Figure 3 depicts an inverse square fall-off with distance for the natural logarithm of the radiation with the highest pixel area averaged to 75% of the peak height.

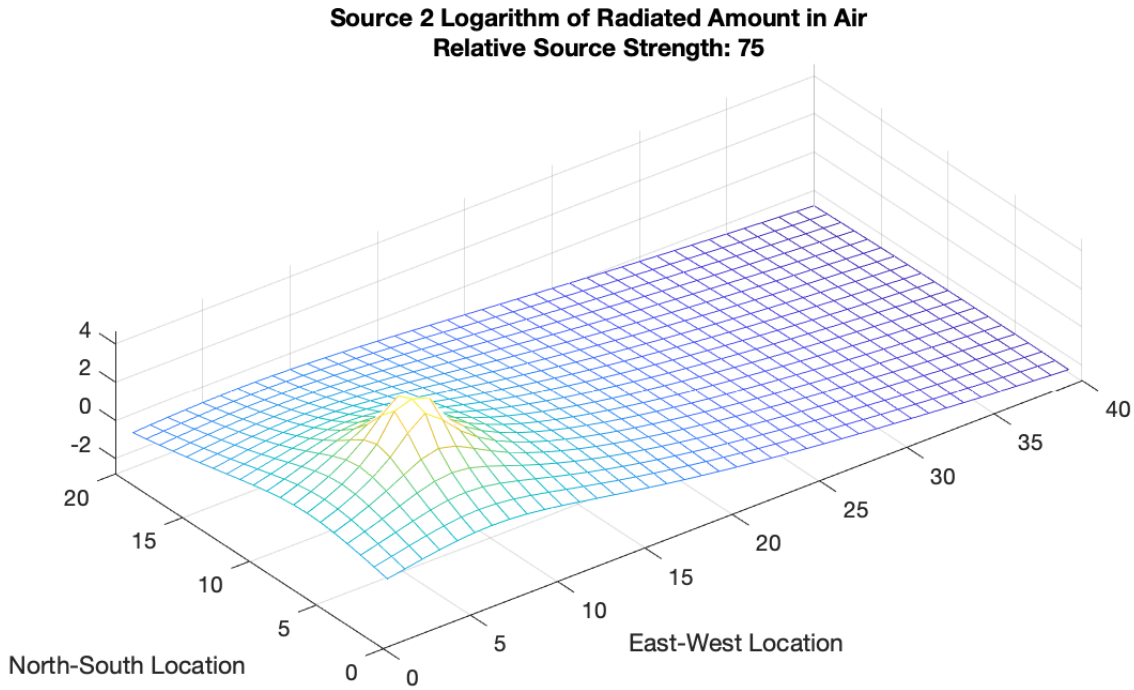


Figure 4: Natural Logarithm of the Radiated Amount from a Source of Strength 75 in Location 2.

Figure 4 depicts an inverse square fall-off with distance for the natural logarithm of the radiation with the highest pixel area averaged to 75% of the peak height.

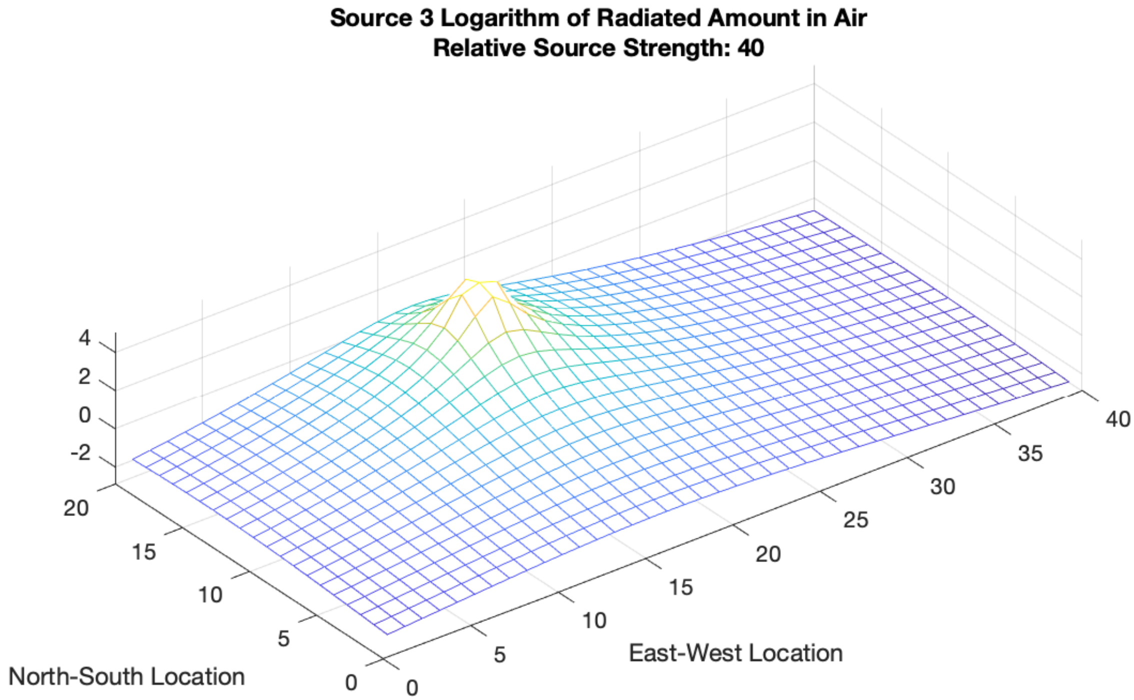


Figure 5: Natural Logarithm of the Radiated Amount from a Source of Strength 40 in Location 3.

Figure 5 depicts an inverse square fall-off with distance for the natural logarithm of the radiation with the highest pixel area averaged to 75% of the peak height.

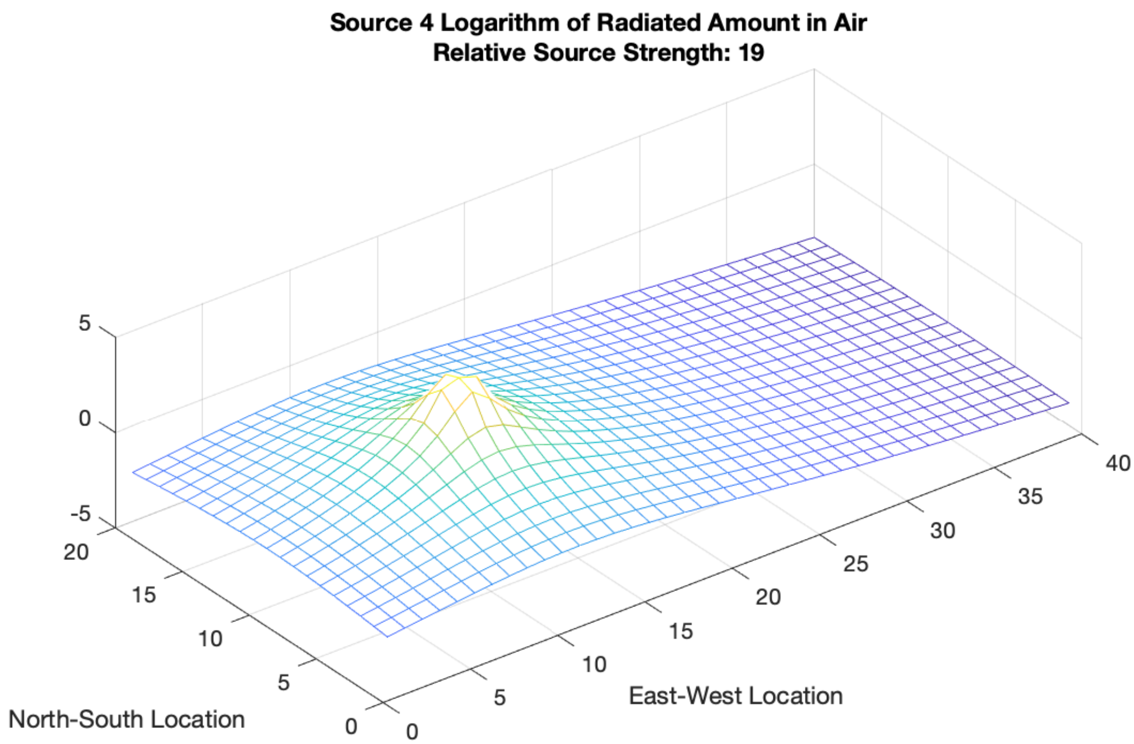


Figure 6: Natural Logarithm of the Radiated Amount from a Source of Strength 19 in Location 4.

Figure 6depicts an inverse square fall-off with distance for the natural logarithm of the radiation with the highest pixel area averaged to 75% of the peak height.

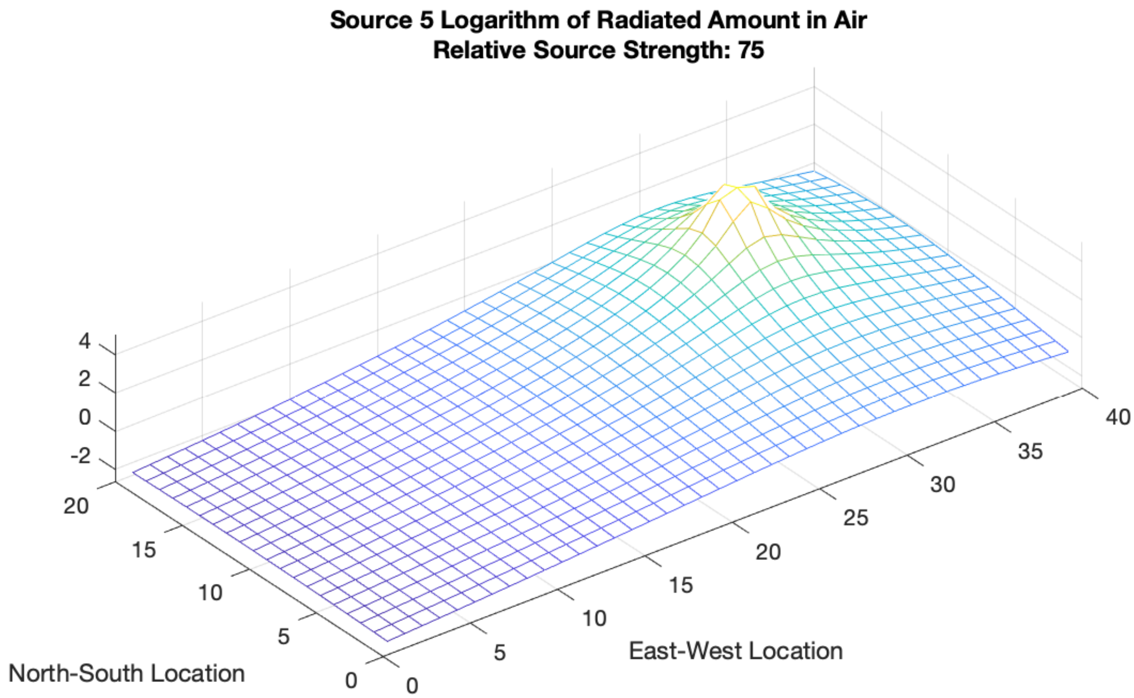


Figure 7: Natural Logarithm of the Radiated Amount from a Source of Strength 75 in Location 5.

Figure 7 depicts an inverse square fall-off with distance for the natural logarithm of the radiation with the highest pixel area averaged to 75% of the peak height.

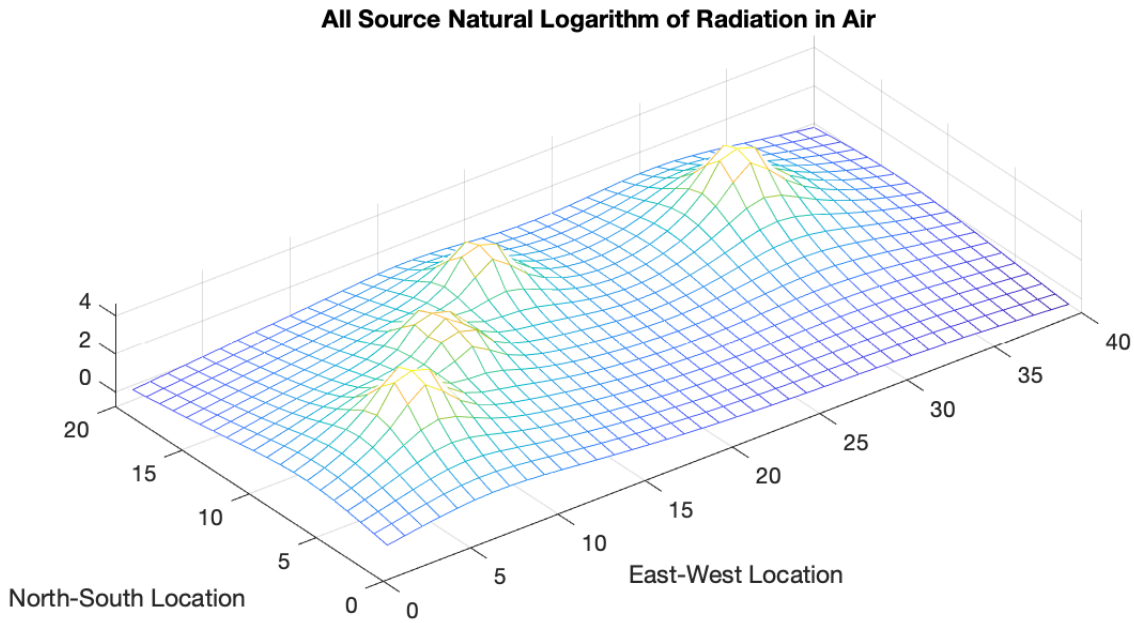


Figure 8: Natural Logarithm of the Sum of the Radiated Amounts in Air for All Sources in their Respective Locations

Figure 8 is the amount of radiation one would see from all sources with no attenuation from the building, no attenuation from the air and inverse square loss of radiation only. With source pixel area set to .75 times the maximum source strength for each source.

Now assuming the building as are 1% concrete and the transmission attenuation of Cesium-137 is .8 per cm for concrete we can compute how much radiation is transmitted though the buildings. The equation for transmission is exp(-.8 x (concrete thickness in cm)) , see [3] and slide 32 of [4]. The resulting transmission amounts are shown in Figures 9-13.

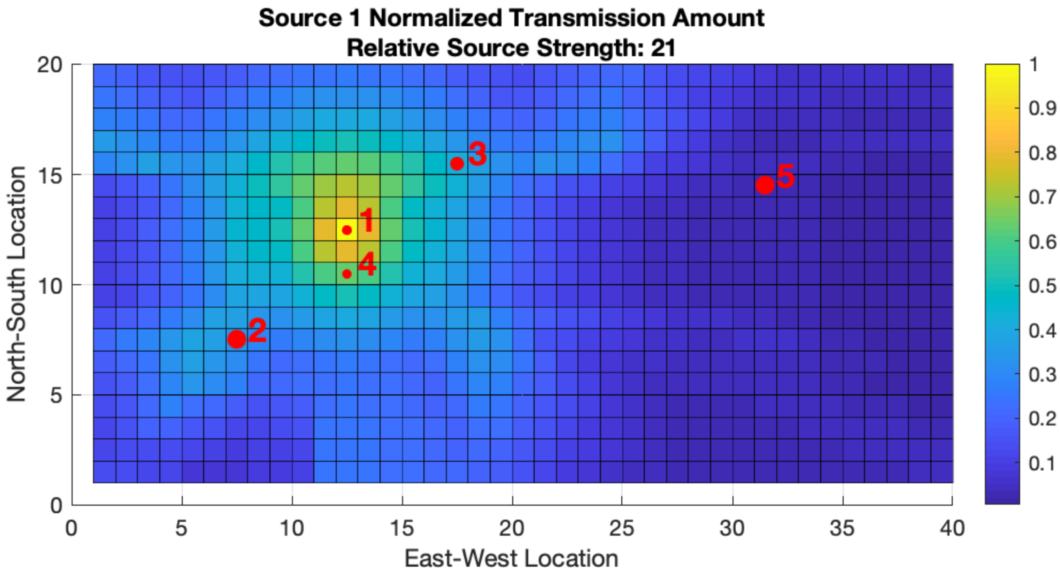


Figure 9: Normalized Transmission of the Source 1 Radiation assuming the buildings may attenuate the radiation.

Figure 9 depicts the normalized decrease in transmission, attenuation, from the source based solely on the amount of concrete separating the source and each pixel area. Shadows of the buildings are evident as well as corridors between buildings.

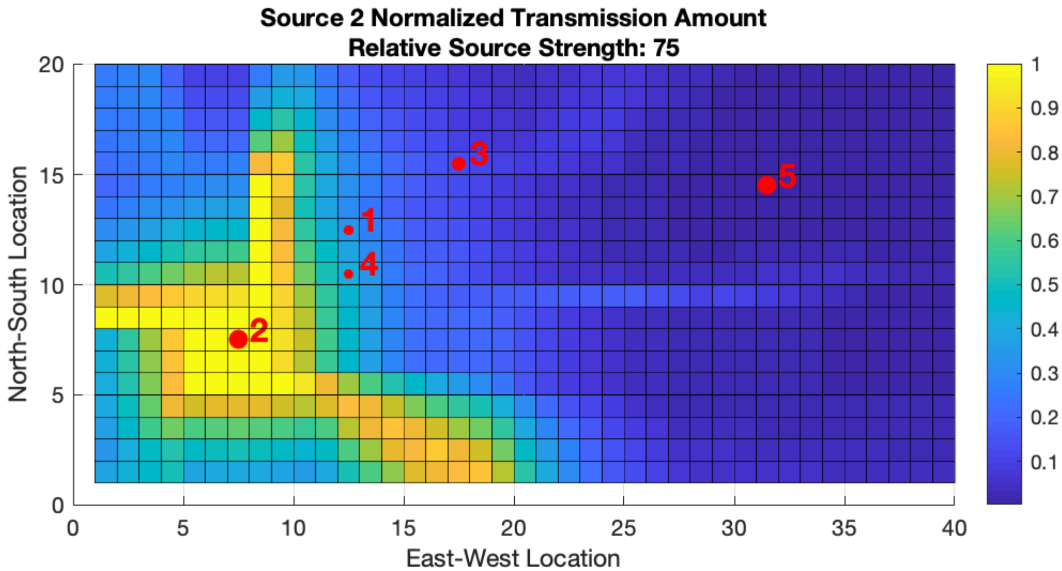


Figure 10: Normalized Transmission of the Source 2 Radiation assuming the buildings may attenuate the radiation.

Figure 10 depicts the normalized decrease in transmission from the source based solely on the amount of concrete separating the source and each pixel area. Shadows of the buildings are evident as well as corridors between buildings. Source 2 has no concrete on its left side producing the yellow ray on the left of Figure 10. The yellow ray shown to the lower right of the source is due to transmission thru only the corners of two buildings, see Figure 2 for the building locations. The ray to the top extends between buildings until partially shielded by the upper building.

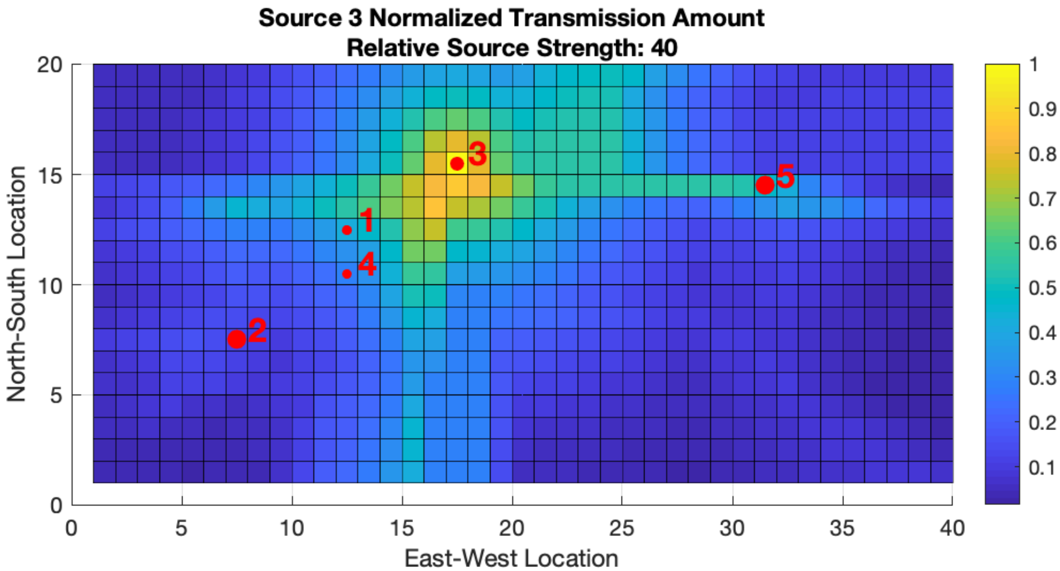


Figure 11: Normalized Transmission of the Source 3 Radiation assuming the buildings may attenuate the radiation.

Figure 11 depicts the normalized decrease in transmission from the source based solely on the amount of concrete separating the source and each pixel area. Shadows of close buildings are evident as well as, along the line of sight of the source, corridors between buildings.

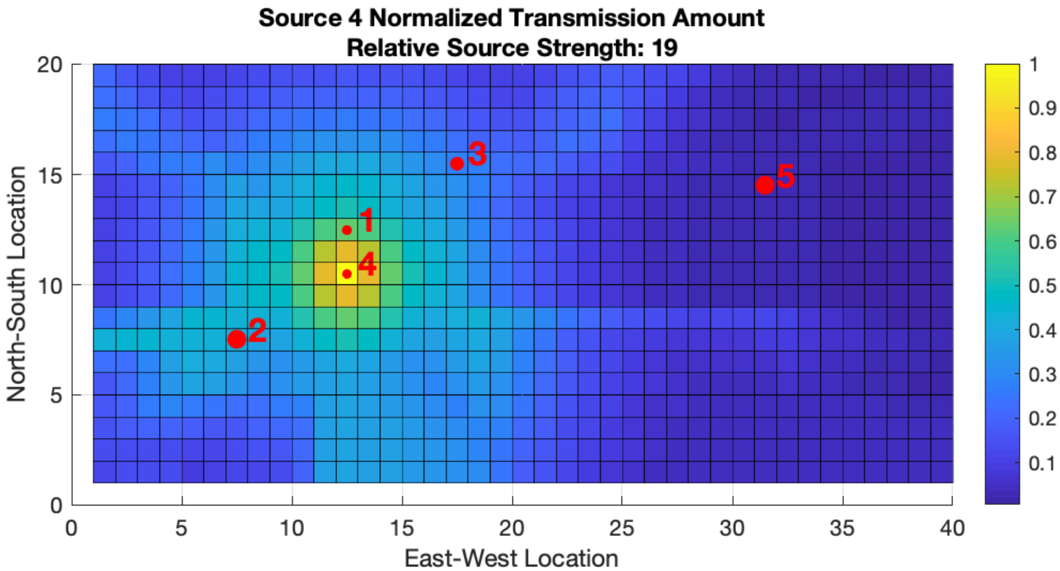


Figure 12: Normalized Transmission of the Source 4 Radiation assuming the buildings may attenuate the radiation.

Figure 12 depicts the normalized decrease in transmission from the source based solely on the amount of concrete separating the source and each pixel area. Shadows of the buildings and corridors between buildings are barely evident.

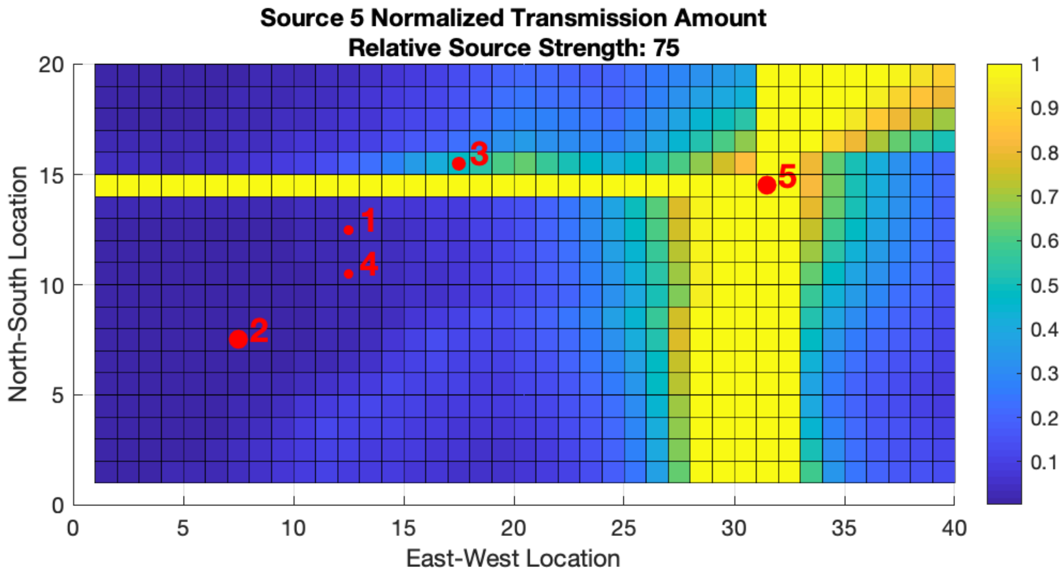


Figure 13: Normalized Transmission of the Source 5 Radiation assuming the buildings may attenuate the radiation.

Figure 13 depicts the normalized decrease in transmission from the source based solely on the amount of concrete separating the source and each pixel area. Shadows of the buildings are evident as well as corridors between buildings. The yellow rays depicted in Figure 13 visually allow for location of the source by triangulation.

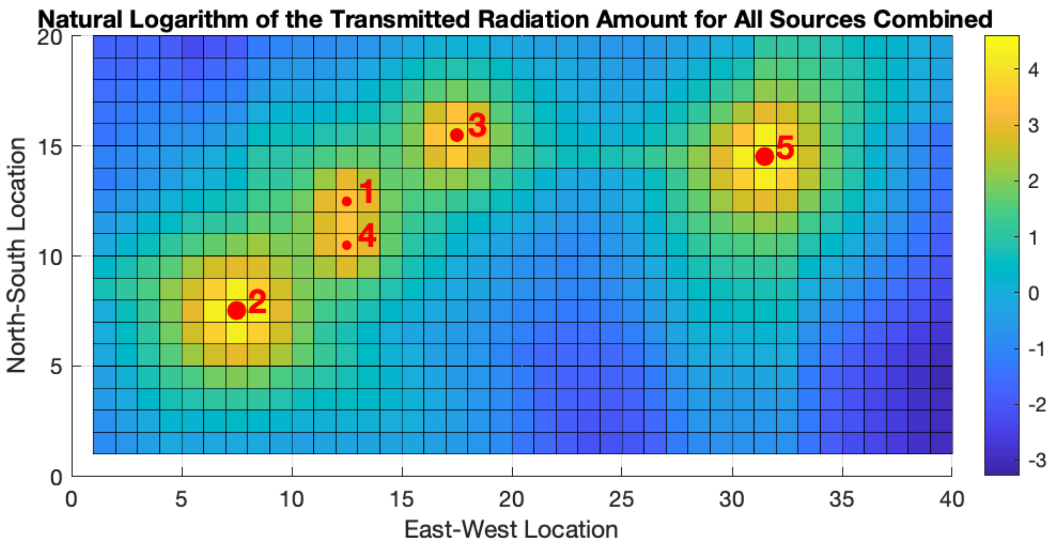


Figure 14: Transmission of the All Sources Radiation assuming the buildings may attenuate the radiation.

Figure 14 depicts the natural logarithm of the aggregation of the radiation and accounting for the transmission from all sources.

4. Conclusion

The graphics portrayed here allow one to visually see why certain sources are stronger in some areas and weaker in other areas. Many questions are raised some of which are addressed in [1] and [2]. A few of these questions are:

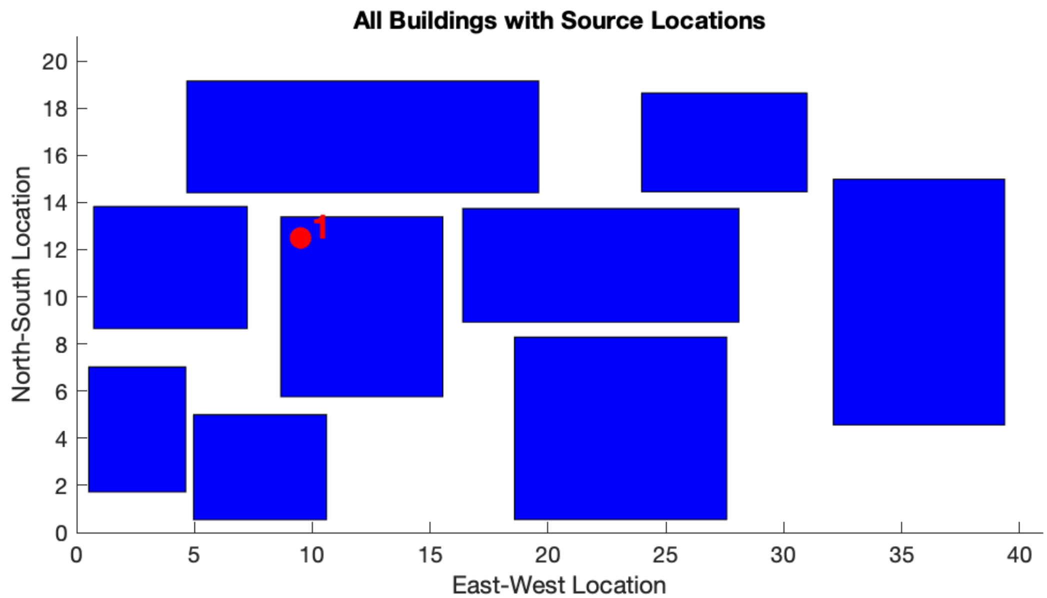
1. Can we tell the difference between two different sources?
2. How accurately can we pinpoint a source?
3. How long do we need to measure the source strength from locations in the area?
4. What locations are best for measurement given the building configuration?
5. What size source may be detected?
6. How do different types of radiation affect the results?
7. On what distance scales may this methodology be used?
8. May we take moving measurements over the area, such as from a vehicle, and use these to determine source strengths and locations?

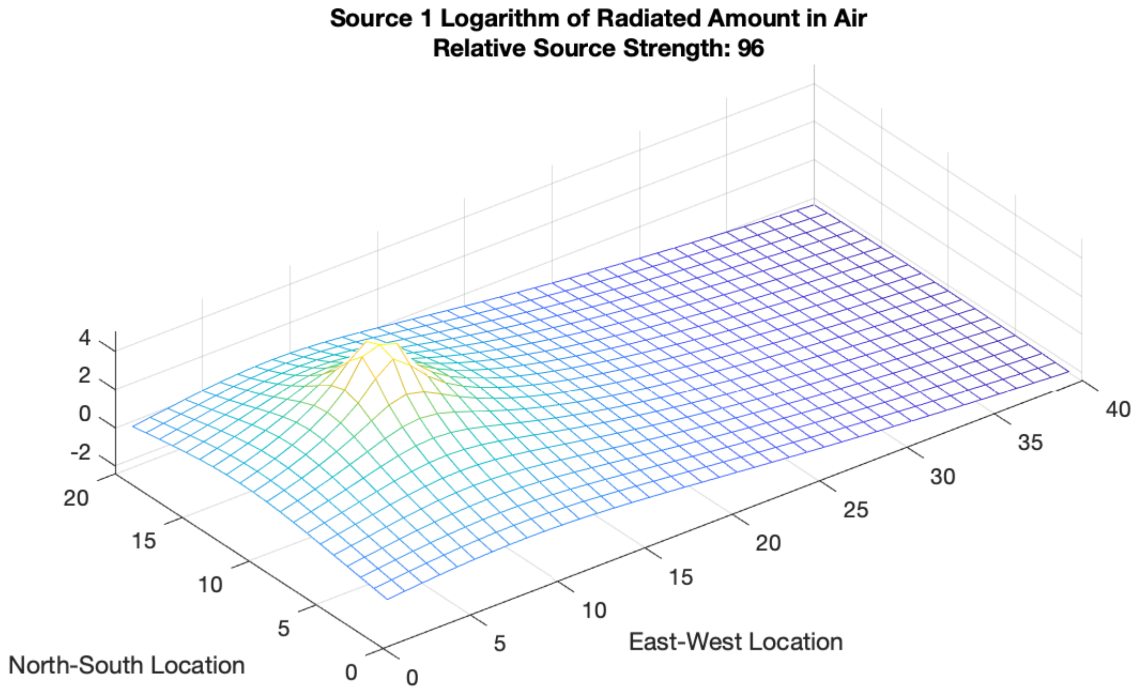
5. References

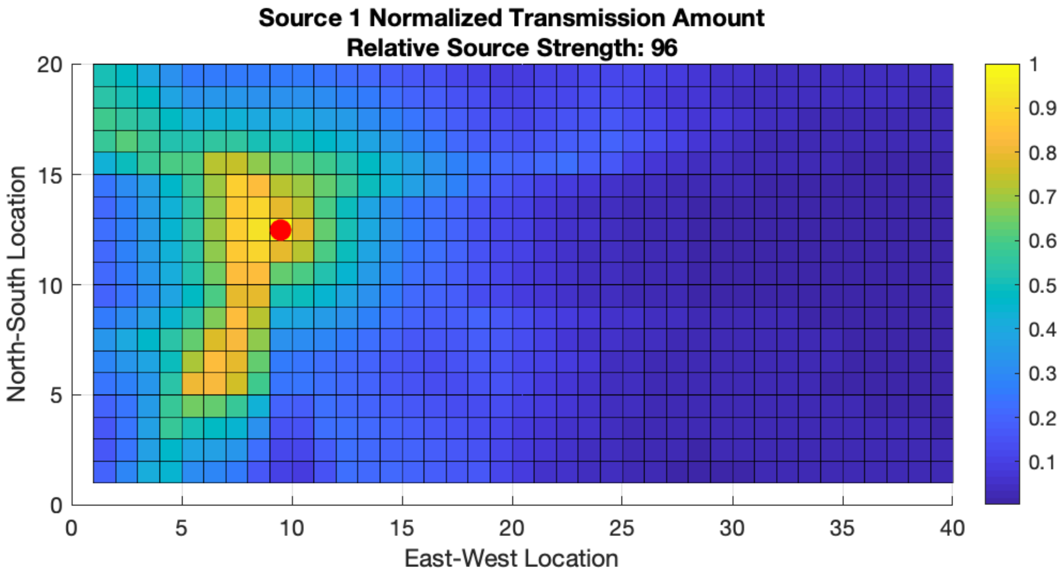
1. Michaud, I. (2019) Simulation-Based Bayesian Experimental Design Using Mutual Information. Ph.D. Thesis, North Carolina State University, Raleigh, NC, USA
2. Ştefănescu, R., Hite, J., Cook, J., Smith, R. C., & Mattingly, J. (2019). Surrogate-Based Robust Design for a Non-Smooth Radiation Source Detection Problem. *Algorithms*, *12*(6), 113
3. G. F. Knoll, (2002) Radiation detection and Measurement, Ann Arbor, University of Michigan
4. nrc.gov (2011) Shielding Radiation Alphas, Betas, Gammas and Neutrons (2011) https://www.nrc.gov/docs/ML1122/ML11229A721.pdf
5. Huda Elnaeim Mohamed Satty (2014). Efficiency of cement – based Low -weight shielding materials for Cs-137 Gamma Rays, B.Sc.in Applied Physics and Mathematics, M.Sc. thesis in Nuclear Science Technology, Nuclear Sciences Program, Omdurman Ahlia University, Sudan Academy of Sciences, Atomic Energy Council, Sudan
6. B. Dogan, and N. Altinsoy, Investigation of photon attenuation coefficient of some building materials used in Turkey, (2015), AIP Conference Proceedings 1653, 020033 (2015); https://doi.org/10.1063/1.4914224
7. V. Fugarua,, S. Berceaa, C. Postolachea, S. Maneaa, A. Moantab, I. Petreb, M. Gheorghec, (2014), Gamma Ray Shielding Properties of Some Concrete Materials, Proceedings of the 4th International Congress APMAS2014, April 24-27, 2014, Fethiye, Turkey

8. **6. Appendix 1: Single Source**

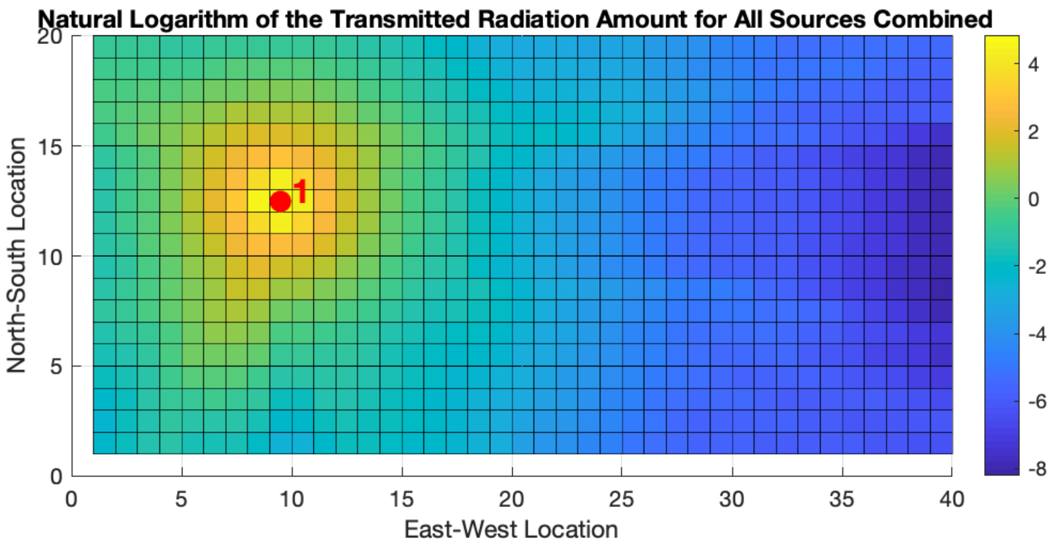
An example for a single source and size of source. See Figures for parameter details.




Source 1 Logarithm of Radiated Amount in Air
Relative Source Strength: 96
4
2
0
-2
20
15
10
5
0
North-South Location
0
5
10
15
20
25
30
35
40
East-West Location



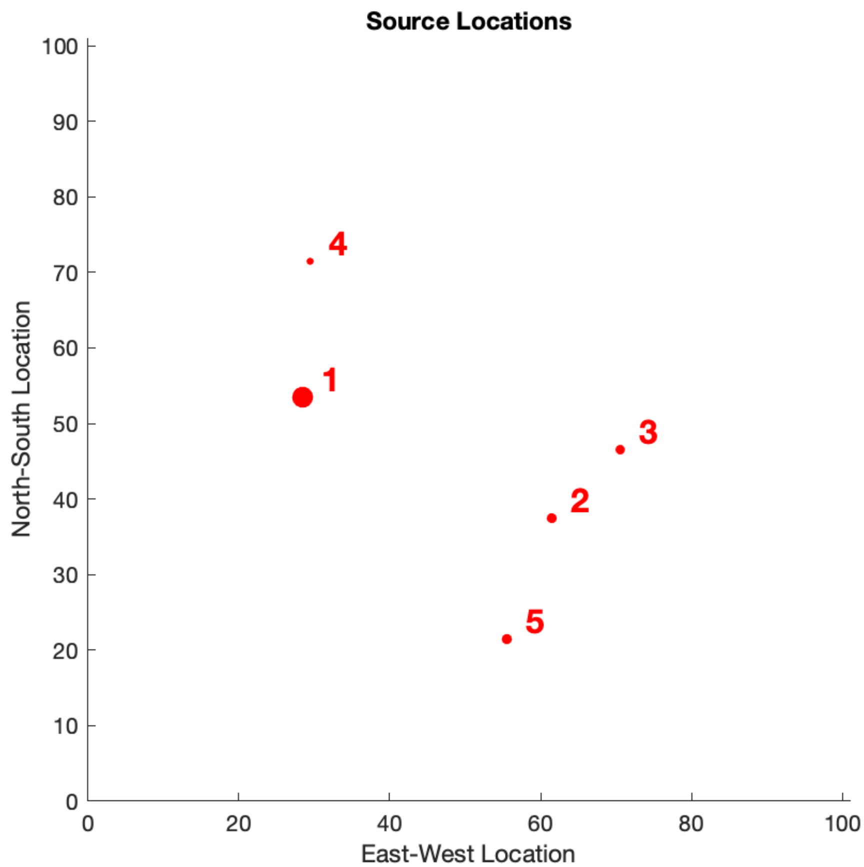
Source 1 Normalized Transmission Amount
Relative Source Strength: 96
North-South Location
East-West Location
0
5
10
15
20
25
30
35
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

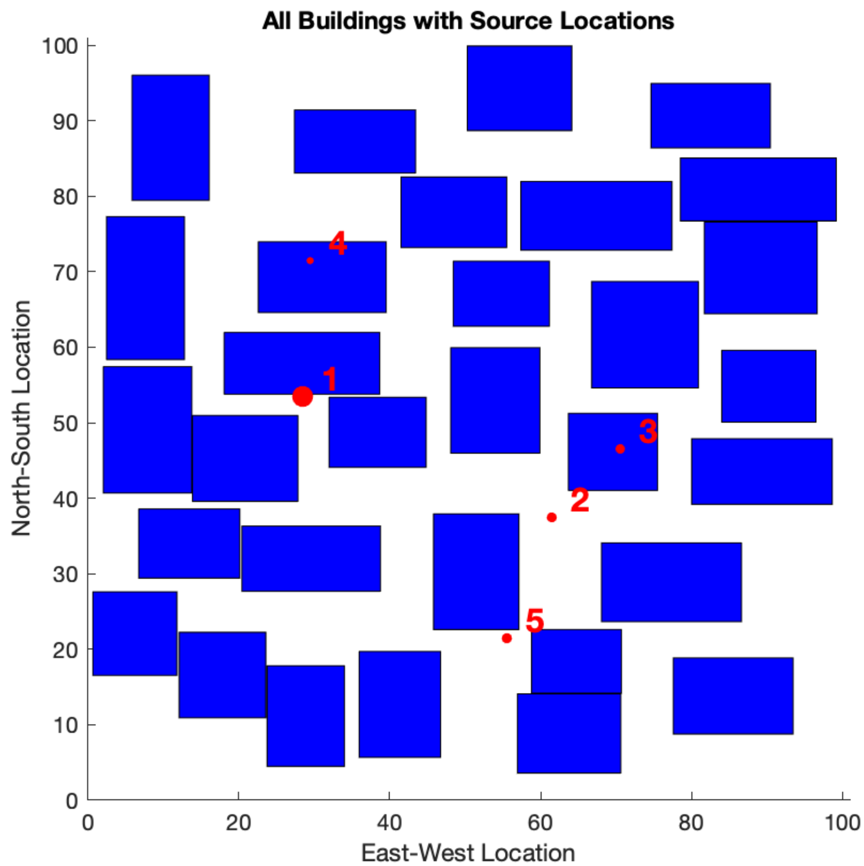


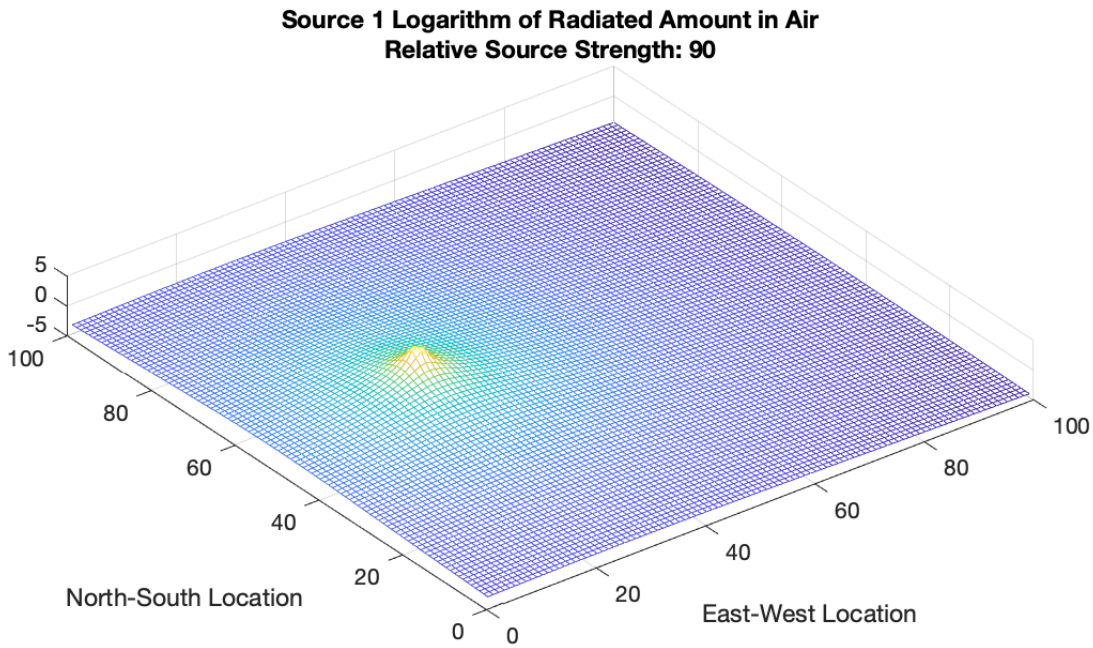
Natural Logarithm of the Transmitted Radiation Amount for All Sources Combined
North-South Location
East-West Location
1
0
5
10
15
20
25
30
35
40
4
2
0
-2
-4
-6
-8

7. Appendix 2: Fine Mesh

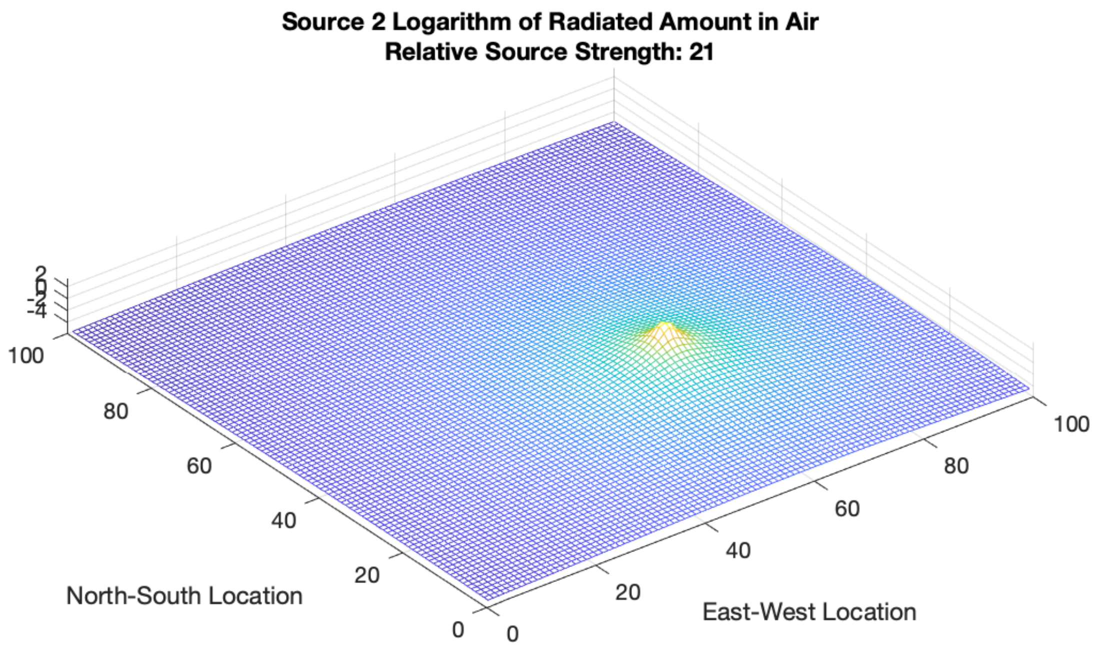
An example with a finer mesh (100 by 100) than in the body of the report, different source constellation and different sizes of sources. See Figures for parameter details.



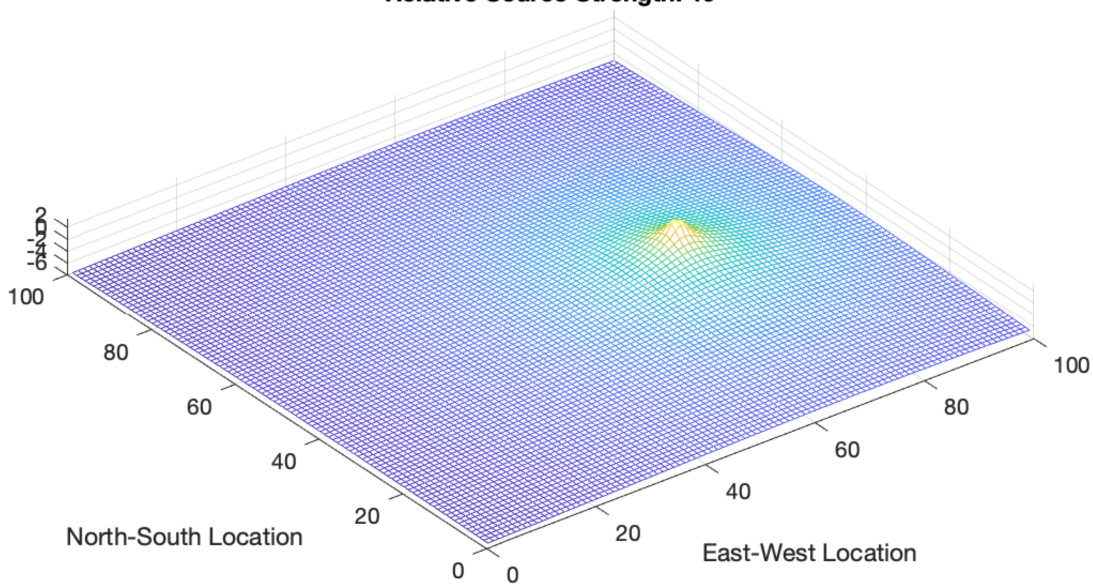

All Buildings with Source Locations
North-South Location
East-West Location
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
1
2
3
4
5

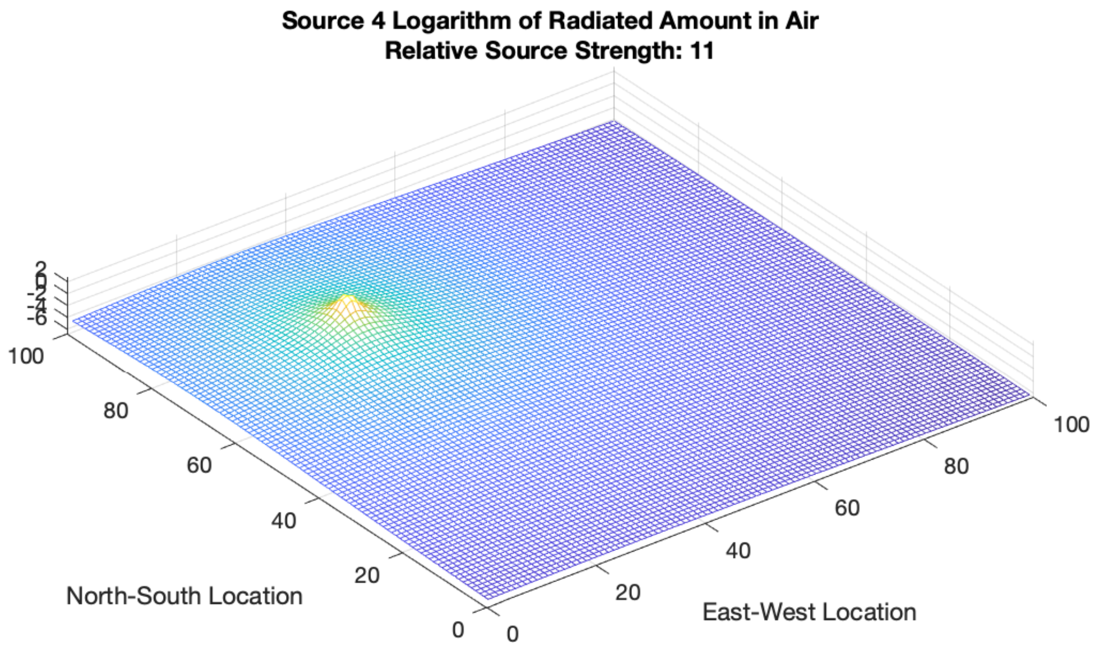


Source 1 Logarithm of Radiated Amount in Air
Relative Source Strength: 90
5
0
-5
100
80
60
40
20
0
North-South Location
0
20
40
60
80
100
East-West Location

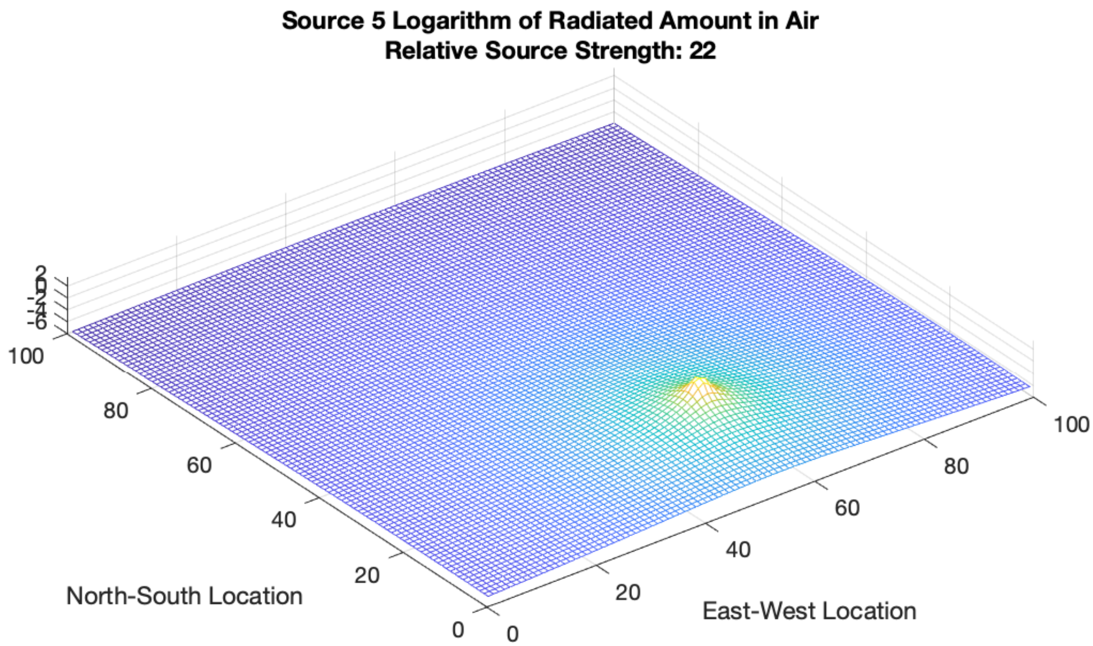

Source 2 Logarithm of Radiated Amount in Air
Relative Source Strength: 21
2
0
-2
-4
100
80
60
40
20
0
North-South Location
0
20
40
60
80
100
East-West Location

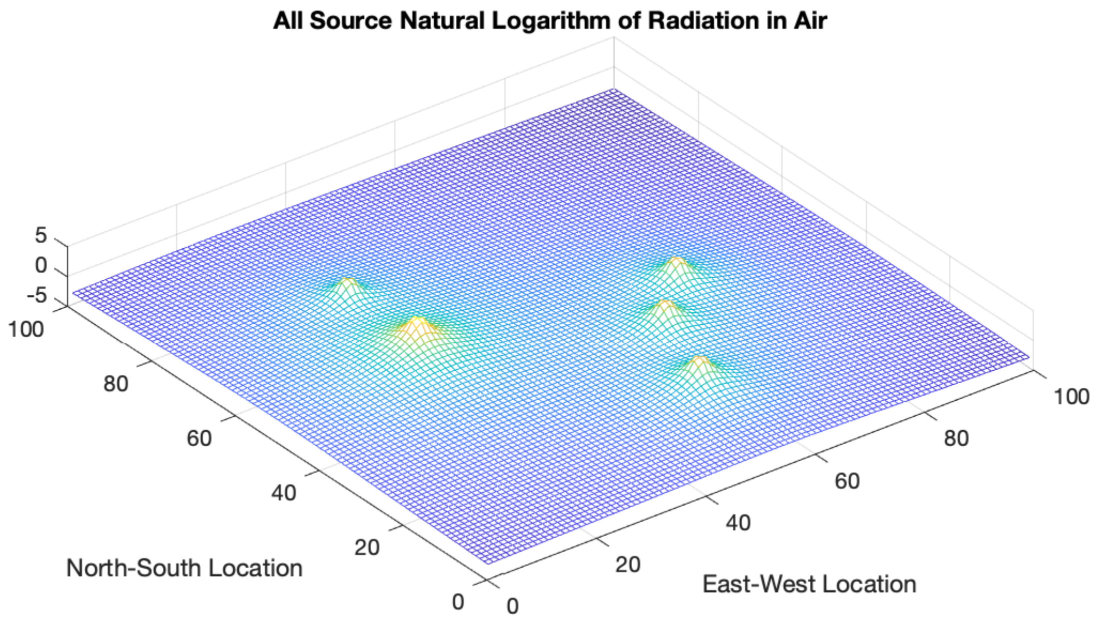
Source 3 Logarithm of Radiated Amount in Air
Relative Source Strength: 19

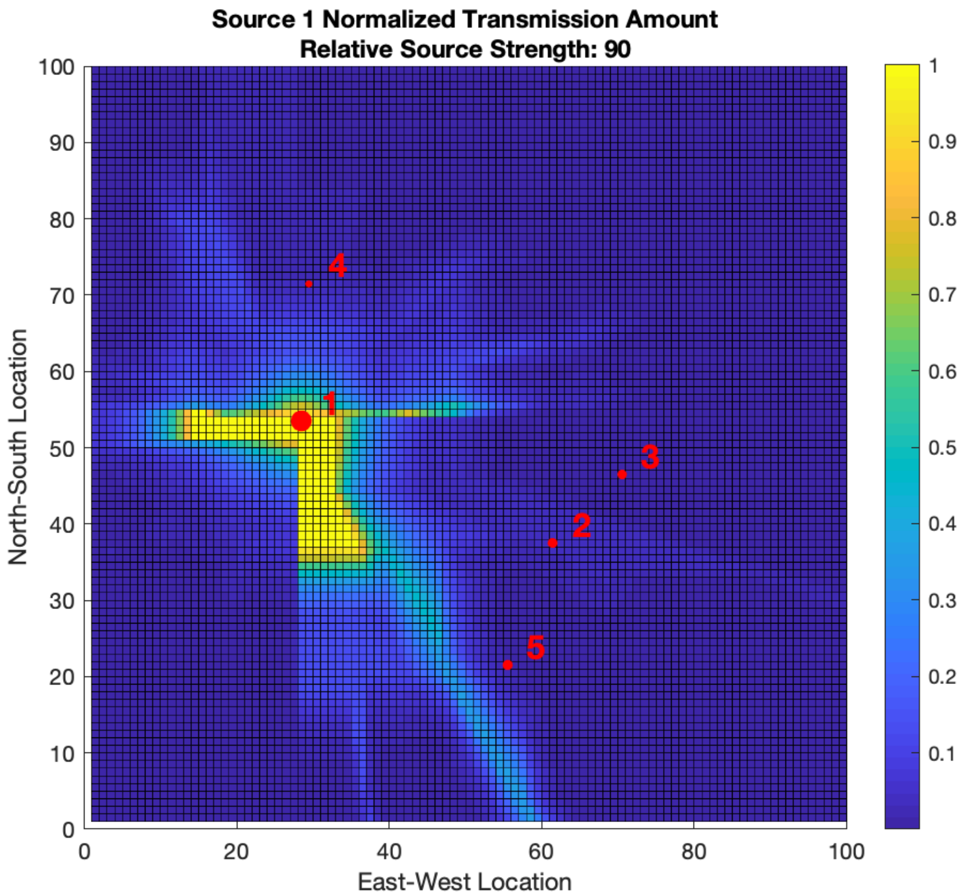


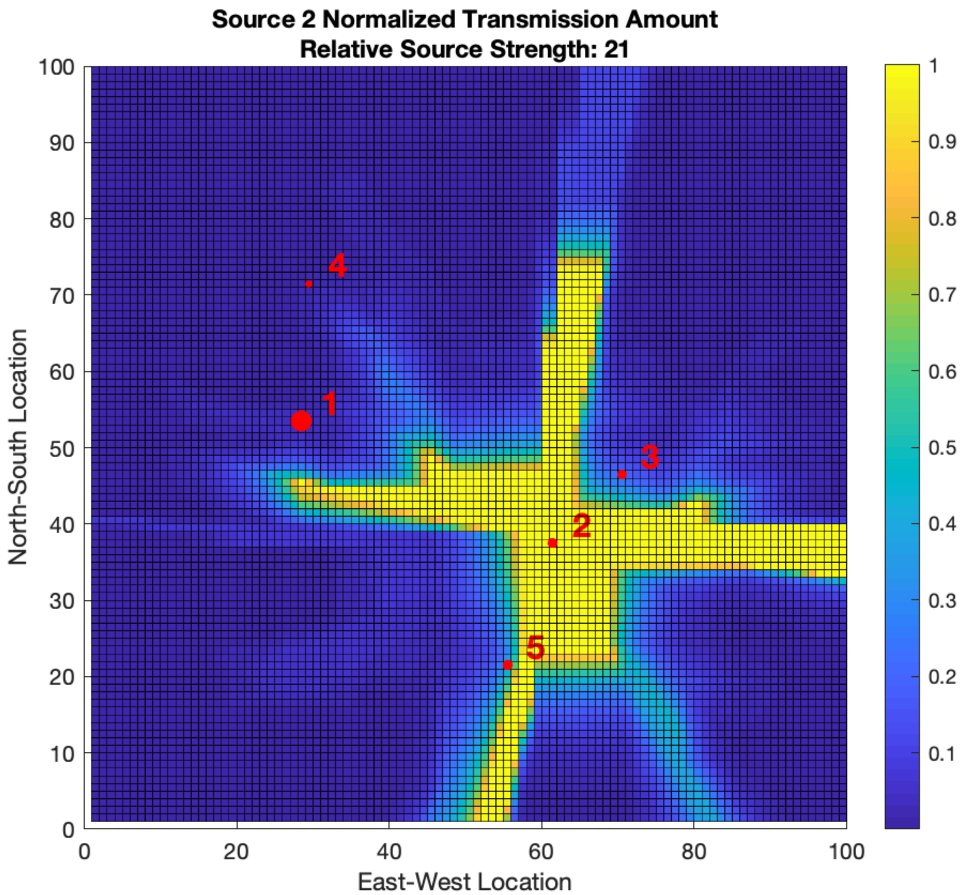


Source 4 Logarithm of Radiated Amount in Air
Relative Source Strength: 11
2
0
-2
-4
-6
100
80
60
40
20
0
North-South Location
0
20
40
60
80
100
East-West Location

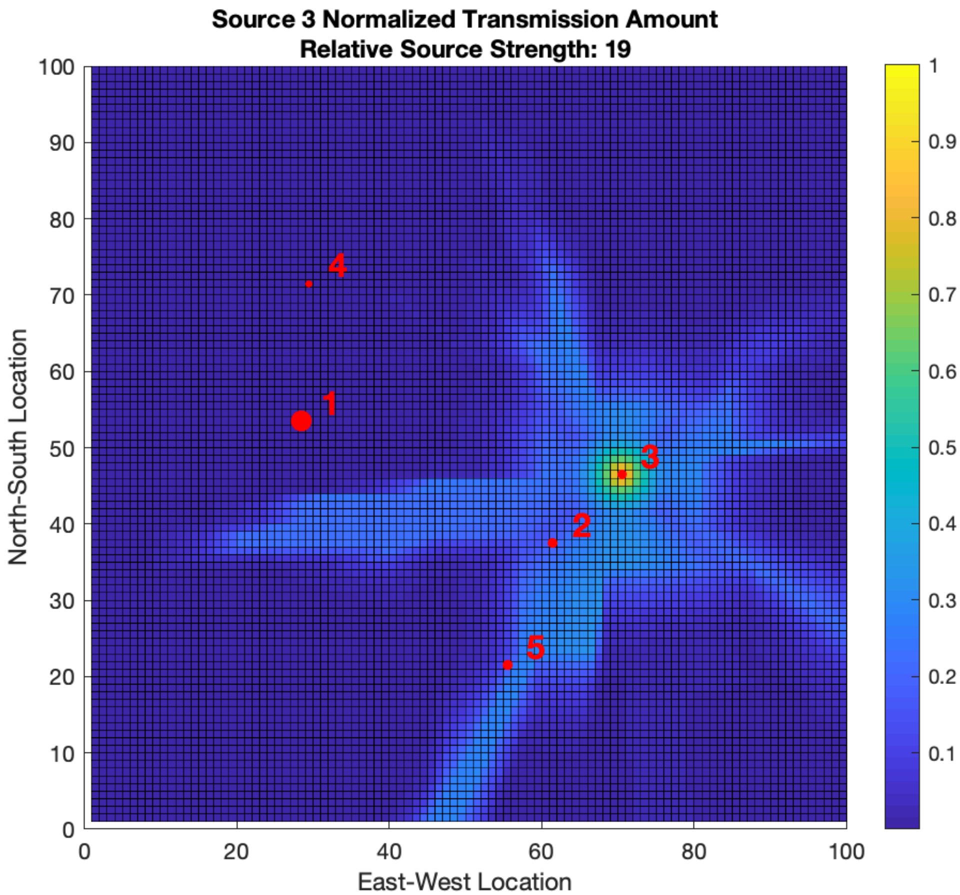

Source 5 Logarithm of Radiated Amount in Air
Relative Source Strength: 22
North-South Location
East-West Location
0
20
40
60
80
100
0
20
40
60
80
100
2
-6

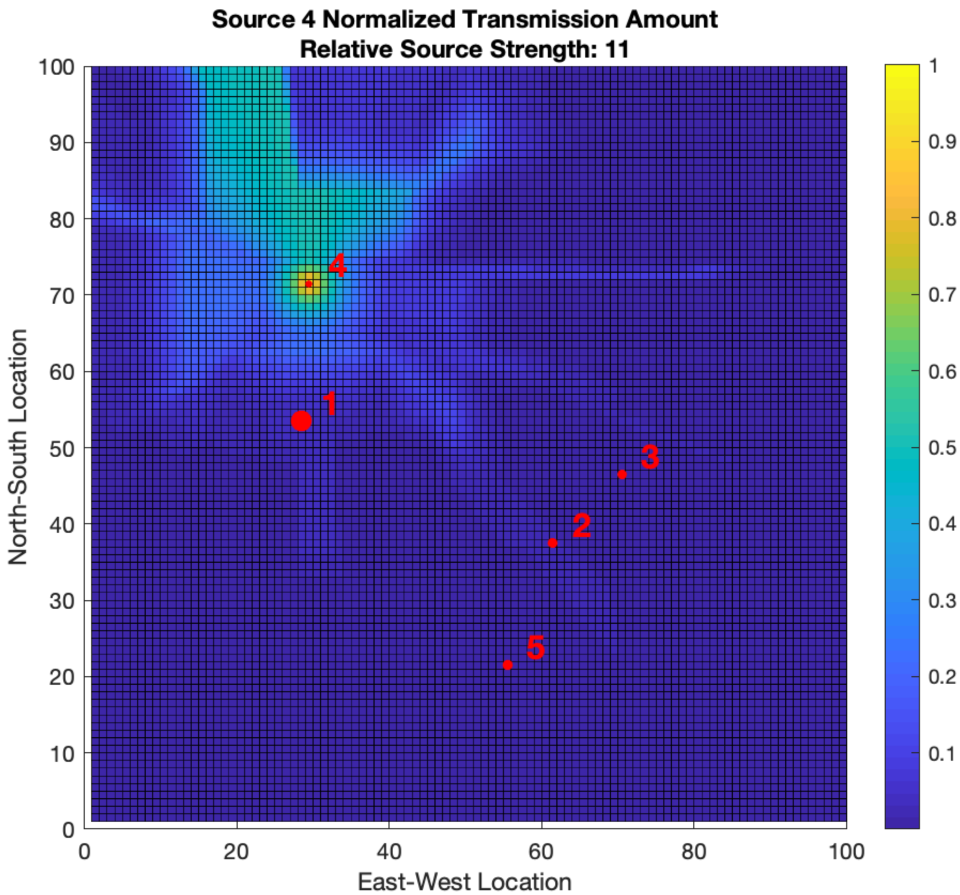

All Source Natural Logarithm of Radiation in Air
5
0
-5
100
80
60
40
20
0
North-South Location
0
20
40
60
80
100
East-West Location


Source 1 Normalized Transmission Amount
Relative Source Strength: 90
North-South Location
East-West Location
1
2
3
4
5
0
20
40
60
80
100
0
10
20
30
40
50
60
70
80
90
100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

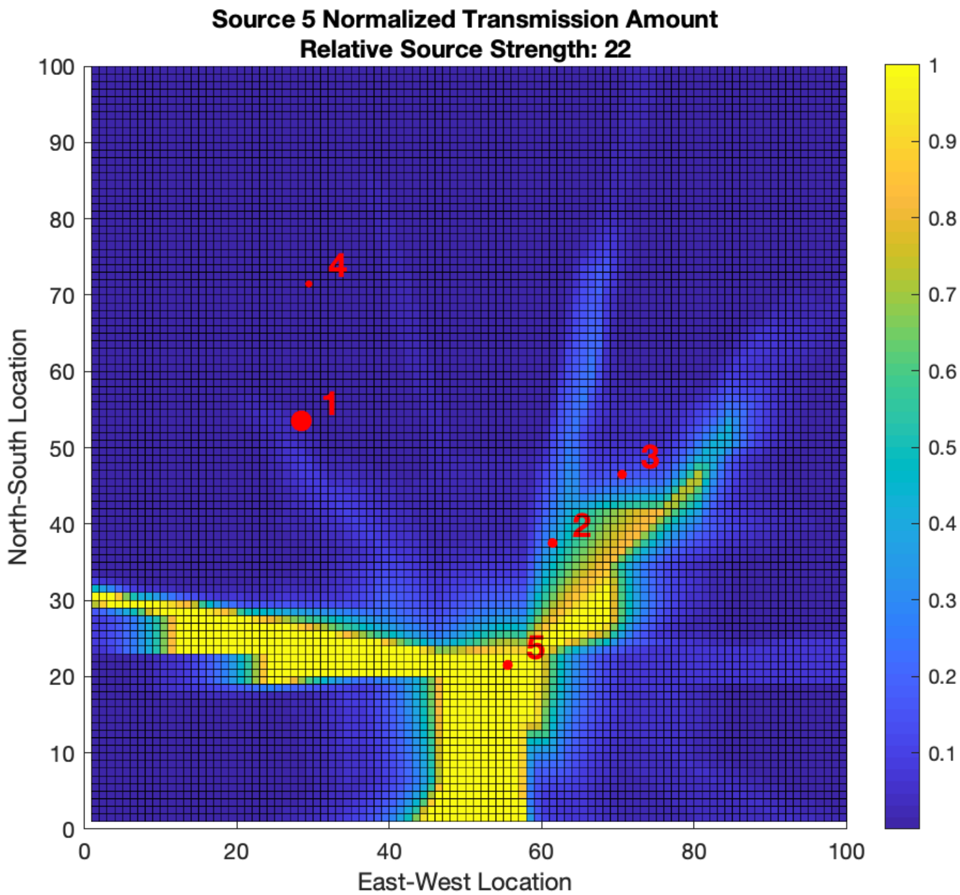


Source 2 Normalized Transmission Amount
Relative Source Strength: 21
North-South Location
East-West Location
0
20
40
60
80
100
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

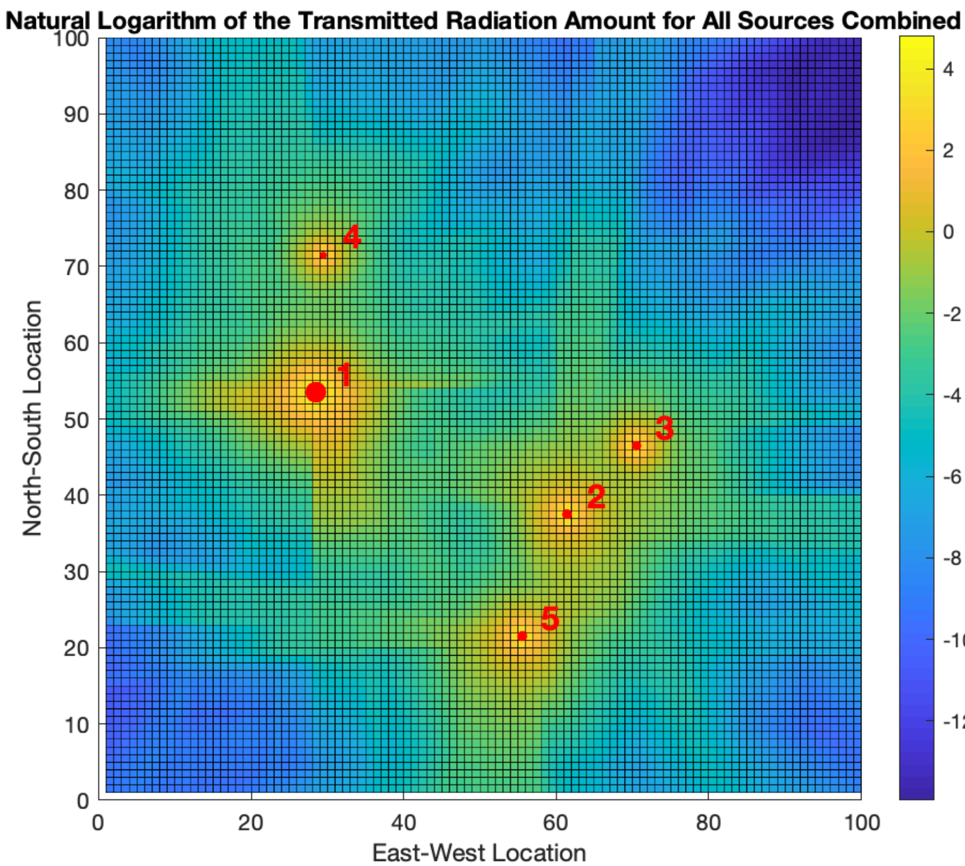

Source 3 Normalized Transmission Amount
Relative Source Strength: 19
North-South Location
East-West Location
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
1
2
3
4
5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Source 4 Normalized Transmission Amount
Relative Source Strength: 11
North-South Location
East-West Location
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
1
2
3
4
5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Source 5 Normalized Transmission Amount
Relative Source Strength: 22
North-South Location
East-West Location
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
1
2
3
4
5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Natural Logarithm of the Transmitted Radiation Amount for All Sources Combined
North-South Location
East-West Location
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
1
2
3
4
5
4
2
0
-2
-4
-6
-8
-10
-12